THE RELATION OF THE BODY TEMPERATURE OF THE EARTHWORM TO THAT OF ITS ENVIRONMENT.

CHARLES G. ROGERS AND ELSIE M. LEWIS.[1]

In a paper by one of us upon the "Temperature Coefficient of the Rate of Heart Beat in Certain Living Animals"[2] the assumption was made that the temperature of the living animal (worm or fish-embryo) under observation corresponded very closely to that of the water surrounding it. The same assumption has been made by other workers in this field, *e. g.*, Snyder[3] in his work upon the isolated heart of the Pacific terrapin assumed that the temperature of the more or less bulky heart muscle of the terrapin was conditioned by the temperature of the solution in which it was placed. Robertson[4] also in his work upon *Ceriodaphnia* assumed that the temperature of the water definitely represented the temperature of the tissues with which he was particularly concerned. Even more recently Loeb and Ewald[5] make use of the same assumption.

There are to be found in the literature of physiology statements concerning the body temperatures of the so-called cold-blooded animals, and an examination of the data offered reveals the fact that the various investigators who have taken the trouble to make any examination of the actual conditions find that the temperatures of the animals studied vary considerably from the temperatures of the surroundings. It is also true that many

[1] From the Department of Zoology, Oberlin College.

[2] Rogers, Charles G., "Studies upon the Temperature Coefficient of the Rate of Heart Beat in Certain Living Animals," *American Journal of Physiology*, 1911, Vol. 28, No. II., pages 81–93.

[3] Snyder, C. D., "On the Influence of Temperature Upon Cardiac Contraction and Its Relation to Influence of Temperature upon Chemical Reaction Velocity," University of California Publications, Physiology, Vol. 2, No. 15, 1905.

[4] Robertson, T. B., "Note on the Influence of Temperature Upon the Rate of the Heart Beat in a Crustacean (*Ceriodaphnia*)," Biological Bulletin, 1906, Vol. X., No. 5, pp. 242–248.

[5] Loeb, Jacques and Ewald, W. F., "Die Frequenz der Herztätigkeit als eindeutige Funktion der Temperatur," *Biochemische Zeitschrift*, 1913, Bd. 58, H 3, 177–185.

of the observations recorded were made by means of mercurial thermometers, though some were made by thermocouples with galvanometers. In reading the statements of the different investigators one is left with the feeling that with the more improved appliances of the present day one ought to be able to make observations which would be more satisfactory than those published. The following table summarizes the results of a number of investigators, and is compiled from data quoted by Milne-Edwards.[1]

Animal.					Authority.
Fishes	less than 1°C.	above	surrounding	water	Milne-Edwards
Frog	0°.32–2°.44	"	"	"	Czermak
Frog	0°.0 –0°.575	"	"	"	Becquerel
Frog	0°.04	"	"	"	Dutrochet
Toad	0°.2	"	"	"	"
Frog	0°.7 –0°.3	"	"	"	Dumeril
Proteus	1°.25	"	"	"	Rudolphi
Proteus	2°.6 –5°.6	"	"	"	Czermak
Crayfish	6°.0	"	"	"	Rudolphi
Maia sq.	0°.3 –0°.9	"	"	"	Valentin
Limax	0°.33–0°.50	"	"	"	Spallanzani
Snail	2°.0	"	"	"	Hunter
Snail	1°.1	"	"	"	Martine
Snail	0°.9	"	"	"	Becquerel
Snail	1°.5 –2°.0	"	"	"	Schnetzler
Aplysia	0°.1 –0°.8	"	"	"	Valentin
Octopus	0°.2 –0°.6	"	"	"	"
Eledone	0°.9	"	"	"	"
Annelids	0°.56–0°.85	"	"	"	Hunter
Lumbricus	1°.11–1°.39	"	"	"	"
Holothuria	0°.2 –0°.6	"	"	"	Valentin
Ophiurian	0°.3	"	"	"	"
Asterias ru.	0°.6	"	"	"	"
Sea Urchin	0°.4 –0°.5	"	"	"	"
Medusa Pelagia	0°.2 –1°.0	"	"	"	"
Medusa Cassiopea	0°.3	"	"	"	"
Actinians	0°.2 –0°.5	"	"	"	"

In the table it will be noted that the temperatures determined for the different animals show, for the most part, rather small variations from that of the surrounding water. In a few cases the variation is quite considerable, and appears to make desirable a reëxamination of the facts. This is especially true in view of

[1] Milne-Edwards, "Leçons sur la Physiologie et L'Anatomie Comparée de L'Homme et des Animaux," T. VIII., Paris, 1863.

the fact that certain scientific friends have raised question as to the validity of the assumption upon which the temperature coefficient work was based. It is with an idea of attempting to answer any questions as to the propriety of assuming that the temperature of the earthworm is represented by the temperature of the surroundings, that the present investigation is here reported.

Methods.

A method of measuring differences of temperature by means of the electromotive force developed when the junctions of wires of different metals of a common circuit are not at the same temperature was described by Nobili and Melloni[1] about 1830. Since that time galvanometers have been made more sensitive, and it has also been made possible to obtain pure metallic wires of small diameter, and of small heat capacity. The authors named were the first to apply this method of temperature measurement to living animals, and now that the methods of use have been somewhat improved the same method has been employed for the measurement of the amount of heat given off in a given contraction of a frog muscle.[2] The method can be made accurate enough to measure differences as small as 1/150° C. For the purpose of the investigation here reported it did not seem necessary to make measurements as small as those recorded by Hill, so the number of junctions of the wires was not at all increased. The thermo-couples used consisted of No. 32 copper and No. 32 constantan wires joined together as shown in Fig. 1. In some of the couples the wires were simply twisted together and in others the junction was made secure by a small drop of solder. We were not able to determine that for our purpose the soldered junctions were any more efficient than those not soldered. The junction used within the body of the worm was mounted within a slender glass tube in such a way as to have the two wires of the couple thoroughly insulated from each other except at the junction point (Fig. 2). This was accomplished by placing

[1] Nobili et Melloni, "Recherches sur plusiers phenomenes calorifiques enterprises au moyen du thermo-multiplcaiteur," *Ann. de chimie et de physique*, 1831, T. XLVIII., p. 208.

[2] Hill, A. V., "The Energy Degraded in the Recovery Process of Stimulated Muscles," *Journal of Physiology*, 1913, Vol. 46, pp. 28–80.

one of the wires in a finely drawn glass tube, allowing the end of the wire to extend slightly below the end of the tube, where it was twisted together with the other wire of the couple. The small glass tube with the two wires was then placed inside another glass tube of a diameter just sufficient to receive them easily. The glass of the outer tube was then sealed over the junction of the wires, and the whole bent into a convenient form for handling. The upper open ends of the tubes were sealed with wax to prevent the access of any water and the apparatus was ready for use.

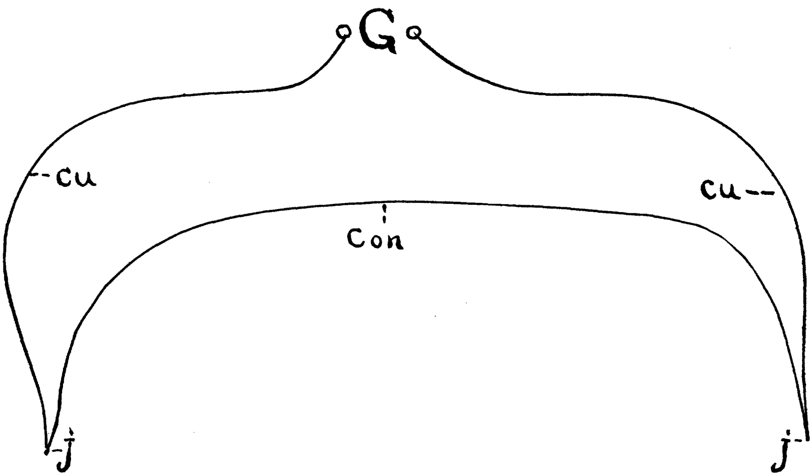

FIG. 1. Diagrammatic scheme of thermocouple. G = galvanometer; *cu* = copper wire; *con* = constantan wire; j = junction.

The galvanometer used in this work was one of the D'Arsonval type made by Gaertner. It was provided with a dead beat coil, and was so heavily damped that it was found desirable to allow two or three minutes for the galvanometer mirror to come to rest when making observations. It was found that with the scale at about 1 meter distance 1° C. difference in the temperature of the two junctions of the thermo-couple was represented by a shifting of the reading of the galvanometer scale by about 16 millimeters. The actual amount of shift varied somewhat from day to day from this value, and was re-determined for each day's work.

The technic of determining the temperature of the interior of

the worm was very simple. It consisted in placing the glass-covered junction of the thermocouple in the mouth of the worm, and carefully pushing it down through the œsophagus, crop and gizzard until it came to lie in the stomach intestine. The other junction of the couple was placed in water of a known temperature, and the two end wires of the thermocouple were attached to the galvanometer. The temperature of the water in which the free junction of the thermocouple was placed was determined by a Beckman thermometer which had been set to a definite reading by the side of a certified standard thermometer. The temperature of the water was determined to 1/100° C., and was noted for every observation so that in case of any variation in the temperature of the water we should be able to make the necessary correction in the results. The temperature of the worm was shown by the amount of the deviation of the galvanometer reading, from the zero reading, divided by the number of millimeters representing 1° C., and adding this amount to the known temperature of the water. In this way we were able to make readings which could be accepted as accurate to within 0.03° C., which for our purpose seemed to be sufficient.

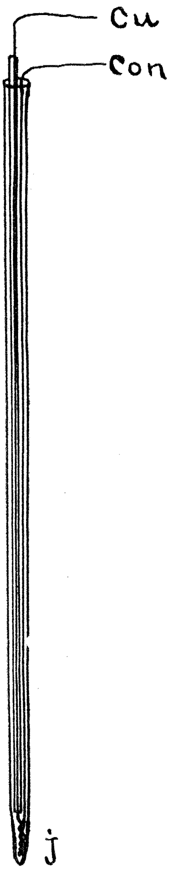

FIG. 2. Sketch of thermo-electric clinical thermometer for use with the earth-worm. *cu* = copper wire; *con* = constantan wire; *j* = junction.

The following table gives data derived from three experiments to show how closely and how rapidly the temperature of the worm becomes adjusted to the temperature of the water in which it is immersed. We have not thought it necessary to multiply examples as all the facts observed are in perfect harmony with those offered. In the experiments here cited both the worm and the free junction of the couple were placed in the same bath. The difference between the zero and in-circuit readings of the

galvanometer would then indicate the difference in temperature between the temperature of the water and the interior temperature of the worm if any such difference exists. After each reading the worm and free junction of the couple were placed in the water of the temperature indicated for the next following reading.

Time.	Temp. of Water in Which Worms Were Placed.	Zero Reading of Galvanometer.	Galvanometer Reading Couple in Circuit.	Difference in Millimeters.	Temperature of Worm.
A. 9.40	11.40° C.	345	345	000	11.40° C.
10.10	21.30	345	345	000	21.30
B. 9.00	21.24	403			
9.17	21.24	403	402	001	21.30
9.25	10.00	403	403	000	10.00
9.35	21.20				
9.40	21.20	408	408	000	21.20
9.55	13.00	408			
10.00	13.00	408	408	000	13.00
C. 10.30	21.20	403	404	001	21.14
10.40	17.00	403	404	001	17.94
10.45	21.20	403	404	001	21.14

The above data are representative of a large number of observations made during an investigation upon the effect of temperature changes upon the rate of contraction of the dorsal blood vessel of the earthworm, *Lumbricus agricola*, and indicate very clearly that the animal under investigation adapts itself with remarkable quickness and closeness to the temperature of its environment. In fact we think it may safely be said that the worm will adapt itself to a change of at least ten degrees Centigrade within two minutes, to an accuracy of 0.05° C. This fact makes it possible then to use the temperature of the water surrounding the animal as an indicator of the temperature of the animal, in the case of the earthworm, for experiments upon the temperature coefficient of heart action, and assures us that the worm need not be subjected to a bath of a given temperature for any great length of time in order to get an accurate result. It is very likely true that the same principle will be found to hold good for other animals of a similar kind and habit, certainly for marine worms, fish embryos, small crustacea, etc. It is the purpose of the authors to continue the investigation upon other

forms in order to determine to what extent we may be at liberty to assume the temperature of the surrounding fluid to be an indicator of the temperature of the tissues.

BIBLIOGRAPHY.

Hill, A. V.

'13 The Energy Degraded in the Recovery Processes of Stimulated Muscles. Journal of Physiology, Vol. 46, pp. 28–80.

Loeb, Jacques and Ewald, W. F.

'13 Die Frequenze der Herztätigkeit als eindeutige Funktion der Temperatur. Biochemisches Zeitschrift, Bd. 58, H. 3, 177–185.

Milne-Edwards.

'63 Lecons sur la Physiologie et L'Anatomie Comparee de L'Homme et des Animaux, T. VIII., Paris.

Nobili et Melloni.

'31 Recherches sur plusiers phenomenes calorifiques enterprises au moyen du thermo-multiplicateur. Ann. de Chimie et de Physique, T. 48, p. 208.

Robertson, T. B.

'06 Note on the Influence of Temperature Upon the Rate of Heart Beat in a Crustacean (*Ceriodaphnia*). BIOLOGICAL BULLITIN, Vol. X, p. 242.

Rogers, Charles G.

'11 Studies upon the Temperature Coefficients of the Rate of Heart Beat in Certain Living Animals. American Journal of Physiology, 1911, Vol. 28, pp. 81–93.

Snyder, Charles D.

'05 On the Influence of Temperature upon Cardiac Contraction and its Relation to Influence of Temperature upon Chemical Reaction Velocity. University of California Publications, Vol. 2, No. 15, pp. 125–146.